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NOTICE OF ALLOWANCE AND FEE(S) DUE

7590	01/26/2005

Corporate Patent Counsel
Philips North America Corporation
580 White Plains Road
Tarrytown, NY 10591

EXAMINER
LE, VU

ART UNIT	PAPER NUMBER
2613	

DATE MAILED: 01/26/2005

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
10/044,876	10/26/2001	Chien-Hsin Lin	US018143	9838

TITLE OF INVENTION: VIDEO ARTIFACT IDENTIFICATION AND COUNTING

APPLN. TYPE	SMALL ENTITY	ISSUE FEE	PUBLICATION FEE	TOTAL FEE(S) DUE	DATE DUE
nonprovisional	NO	$1400	$300	$1700	04/26/2005

THE APPLICATION IDENTIFIED ABOVE HAS BEEN EXAMINED AND IS ALLOWED FOR ISSUANCE AS A PATENT. PROSECUTION ON THE MERITS IS CLOSED. THIS NOTICE OF ALLOWANCE IS NOT A GRANT OF PATENT RIGHTS. THIS APPLICATION IS SUBJECT TO WITHDRAWAL FROM ISSUE AT THE INITIATIVE OF THE OFFICE OR UPON PETITION BY THE APPLICANT. SEE 37 CFR 1.313 AND MPEP 1308.

THE ISSUE FEE AND PUBLICATION FEE (IF REQUIRED) MUST BE PAID WITHIN THREE MONTHS FROM THE MAILING DATE OF THIS NOTICE OR THIS APPLICATION SHALL BE REGARDED AS ABANDONED. THIS STATUTORY PERIOD CANNOT BE EXTENDED. SEE 35 U.S.C. 151. THE ISSUE FEE DUE INDICATED ABOVE REFLECTS A CREDIT FOR ANY PREVIOUSLY PAID ISSUE FEE APPLIED IN THIS APPLICATION. THE PTOL-85B (OR AN EQUIVALENT) MUST BE RETURNED WITHIN THIS PERIOD EVEN IF NO FEE IS DUE OR THE APPLICATION WILL BE REGARDED AS ABANDONED.

HOW TO REPLY TO THIS NOTICE:

I. Review the SMALL ENTITY status shown above.

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II. PART B - FEE(S) TRANSMITTAL should be completed and returned to the United States Patent and Trademark Office (USPTO) with your ISSUE FEE and PUBLICATION FEE (if required). Even if the fee(s) have already been paid, Part B - Fee(s) Transmittal should be completed and returned. If you are charging the fee(s) to your deposit account, section "4b" of Part B - Fee(s) Transmittal should be completed and an extra copy of the form should be submitted.

III. All communications regarding this application must give the application number. Please direct all communications prior to issuance to Mail Stop ISSUE FEE unless advised to the contrary.

IMPORTANT REMINDER: Utility patents issuing on applications filed on or after Dec. 12, 1980 may require payment of maintenance fees. It is patentee's responsibility to ensure timely payment of maintenance fees when due.

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PTOL-85 (Rev. 12/04) Approved for use through 04/30/2007.

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7590   01/26/2005

Corporate Patent Counsel
Philips North America Corporation
580 White Plains Road
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I hereby certify that this Fee(s) Transmittal is being deposited with the United States Postal Service with sufficient postage for first class mail in an envelope addressed to the Mail Stop ISSUE FEE address above, or being facsimile transmitted to the USPTO (703) 746-4000, on the date indicated below.

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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
10/044,876	10/26/2001	Chien-Hsin Lin	US018143	9838

TITLE OF INVENTION: VIDEO ARTIFACT IDENTIFICATION AND COUNTING

APPLN. TYPE	SMALL ENTITY	ISSUE FEE	PUBLICATION FEE	TOTAL FEE(S) DUE	DATE DUE
nonprovisional	NO	$1400	$300	$1700	04/26/2005

EXAMINER	ART UNIT	CLASS-SUBCLASS
LE, VU	2613	375-240290

1. Change of correspondence address or indication of "Fee Address" (37 CFR 1.363).

❑ Change of correspondence address (or Change of Correspondence Address form PTO/SB/122) attached.

❑ "Fee Address" indication (or "Fee Address" Indication form PTO/SB/47; Rev 03-02 or more recent) attached. **Use of a Customer Number is required.**

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(2) the name of a single firm (having as a member a registered attorney or agent) and the names of up to 2 registered patent attorneys or agents. If no name is listed, no name will be printed.

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3. ASSIGNEE NAME AND RESIDENCE DATA TO BE PRINTED ON THE PATENT (print or type)

PLEASE NOTE: Unless an assignee is identified below, no assignee data will appear on the patent. If an assignee is identified below, the document has been filed for recordation as set forth in 37 CFR 3.11. Completion of this form is NOT a substitute for filing an assignment.

(A) NAME OF ASSIGNEE

(B) RESIDENCE: (CITY and STATE OR COUNTRY)

Please check the appropriate assignee category or categories (will not be printed on the patent) : ❑ Individual ❑ Corporation or other private group entity ❑ Government

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❑ Publication Fee (No small entity discount permitted)

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❑ Payment by credit card. Form PTO-2038 is attached.

❑ The Director is hereby authorized by charge the required fee(s), or credit any overpayment, to Deposit Account Number _____ (enclose an extra copy of this form).

5. Change in Entity Status (from status indicated above)

❑ a. Applicant claims SMALL ENTITY status. See 37 CFR 1.27.

❑ b. Applicant is no longer claiming SMALL ENTITY status. See 37 CFR 1.27(g)(2).

The Director of the USPTO is requested to apply the Issue Fee and Publication Fee (if any) or to re-apply any previously paid issue fee to the application identified above. NOTE: The Issue Fee and Publication Fee (if required) will not be accepted from anyone other than the applicant; a registered attorney or agent; or the assignee or other party in interest as shown by the records of the United States Patent and Trademark Office.

Authorized Signature _____

Date _____

Typed or printed name _____

Registration No. _____

UNITED STATES PATENT AND TRADEMARK OFFICE

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
10/044,876	10/26/2001	Chien-Hsin Lin	US018143	9838

7590 01/26/2005	EXAMINER
Corporate Patent Counsel	LE, VU
Philips North America Corporation	

ART UNIT	PAPER NUMBER
2613	

Corporate Patent Counsel
Philips North America Corporation
580 White Plains Road
Tarrytown, NY 10591

DATE MAILED: 01/26/2005

Determination of Patent Term Adjustment under 35 U.S.C. 154 (b)
(application filed on or after May 29, 2000)

The Patent Term Adjustment to date is 762 day(s). If the issue fee is paid on the date that is three months after the mailing date of this notice and the patent issues on the Tuesday before the date that is 28 weeks (six and a half months) after the mailing date of this notice, the Patent Term Adjustment will be 762 day(s).

If a Continued Prosecution Application (CPA) was filed in the above-identified application, the filing date that determines Patent Term Adjustment is the filing date of the most recent CPA.

Applicant will be able to obtain more detailed information by accessing the Patent Application Information Retrieval (PAIR) WEB site (http://pair.uspto.gov).

Any questions regarding the Patent Term Extension or Adjustment determination should be directed to the Office of Patent Legal Administration at (571) 272-7702. Questions relating to issue and publication fee payments should be directed to the Customer Service Center of the Office of Patent Publication at (703) 305-8283.

PTOL-85 (Rev. 12/04) Approved for use through 04/30/2007.

	Application No.	Applicant(s)
Notice of Allowability	10/044,876	LIN ET AL.
	Examiner	Art Unit
	Vu Le	2613

-- The MAILING DATE of this communication appears on the cover sheet with the correspondence address--

All claims being allowable, PROSECUTION ON THE MERITS IS (OR REMAINS) CLOSED in this application. If not included herewith (or previously mailed), a Notice of Allowance (PTOL-85) or other appropriate communication will be mailed in due course. **THIS NOTICE OF ALLOWABILITY IS NOT A GRANT OF PATENT RIGHTS.** This application is subject to withdrawal from issue at the initiative of the Office or upon petition by the applicant. See 37 CFR 1.313 and MPEP 1308.

1. ☒ This communication is responsive to *Preliminary Amendment filed 2/20/02*.

2. ☒ The allowed claim(s) is/are *1-14*.

3. ☒ The drawings filed on <u>20 May 2002</u> are accepted by the Examiner.

4. ☐ Acknowledgment is made of a claim for foreign priority under 35 U.S.C. § 119(a)-(d) or (f).

    a) ☐ All   b) ☐ Some*   c) ☐ None of the:

       1. ☐ Certified copies of the priority documents have been received.

       2. ☐ Certified copies of the priority documents have been received in Application No. _____ .

       3. ☐ Copies of the certified copies of the priority documents have been received in this national stage application from the International Bureau (PCT Rule 17.2(a)).

    * Certified copies not received: _____ .

Applicant has THREE MONTHS FROM THE "MAILING DATE" of this communication to file a reply complying with the requirements noted below. Failure to timely comply will result in ABANDONMENT of this application. **THIS THREE-MONTH PERIOD IS NOT EXTENDABLE.**

5. ☐ A SUBSTITUTE OATH OR DECLARATION must be submitted. Note the attached EXAMINER'S AMENDMENT or NOTICE OF INFORMAL PATENT APPLICATION (PTO-152) which gives reason(s) why the oath or declaration is deficient.

6. ☐ CORRECTED DRAWINGS (as "replacement sheets") must be submitted.

    (a) ☐ including changes required by the Notice of Draftsperson's Patent Drawing Review (PTO-948) attached

       1) ☐ hereto or 2) ☐ to Paper No./Mail Date _____.

    (b) ☐ including changes required by the attached Examiner's Amendment / Comment or in the Office action of Paper No./Mail Date _____.

    Identifying indicia such as the application number (see 37 CFR 1.84(c)) should be written on the drawings in the front (not the back) of each sheet. Replacement sheet(s) should be labeled as such in the header according to 37 CFR 1.121(d).

7. ☐ DEPOSIT OF and/or INFORMATION about the deposit of BIOLOGICAL MATERIAL must be submitted. Note the attached Examiner's comment regarding REQUIREMENT FOR THE DEPOSIT OF BIOLOGICAL MATERIAL.

Attachment(s)

1. ☒ Notice of References Cited (PTO-892)

2. ☐ Notice of Draftperson's Patent Drawing Review (PTO-948)

3. ☒ Information Disclosure Statements (PTO-1449 or PTO/SB/08), Paper No./Mail Date <u>10/03</u>

4. ☐ Examiner's Comment Regarding Requirement for Deposit of Biological Material

5. ☐ Notice of Informal Patent Application (PTO-152)

6. ☐ Interview Summary (PTO-413), Paper No./Mail Date _____ .

7. ☐ Examiner's Amendment/Comment

8. ☒ Examiner's Statement of Reasons for Allowance

9. ☐ Other _____ .

Allowable Subject Matter

1.   Claims 1-14 are allowed.

2.   The following is an examiner's statement of reasons for allowance:

The prior art (WO 01/20912) closest to the present invention belongs to the same

assignee. The prior art and the present invention utilize similar algorithm for identifying

block artifacts in the digital video pictures. However, Examiner fails to ascertain from

the prior art disclosure or suggestion the limitations of "…using first and second loops

for each of horizontal and vertical count table entries, the first loop being adapted to

increase the count table entries up to the length of a remainder value of a detected

artifact value and the second loop being adapted to increase the count table entries

using a quotient value of a detected artifact value" as recited in claim 1.

Any comments considered necessary by applicant must be submitted no later

than the payment of the issue fee and, to avoid processing delays, should preferably

accompany the issue fee. Such submissions should be clearly labeled "Comments on

Statement of Reasons for Allowance."
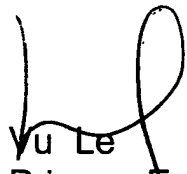
Contact

3.   Any inquiry concerning this communication or earlier communications from the

examiner should be directed to Vu Le whose telephone number is 703-308-6613. The

examiner can normally be reached on M-F 8:30-6:00.

If attempts to reach the examiner by telephone are unsuccessful, the examiner's

supervisor, Chris Kelley can be reached on 703-305-4856. The fax phone number for

the organization where this application or proceeding is assigned is 703-872-9306.

Information regarding the status of an application may be obtained from the

Patent Application Information Retrieval (PAIR) system. Status information for

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you have questions on access to the Private PAIR system, contact the Electronic

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Vu Le
Primary Examiner
AU 2613
(703) 308-6613
Vu.Le@uspto.gov

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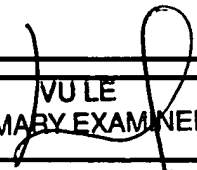
INFORMATION DISCLOSURE STATEMENT BY APPLICANT

Application Number	10/044876
Filing Date	10/26/2001
First Named Inventor	LIN, CHIEN-HSIN
Art Unit	~~2631~~ 2613
Examiner Name	
Attorney Docket Number	US01 8143

U.S. PATENT DOCUMENTS

Examiner Initials*	Cite No.[1]	Document Number No.-Kind Code[2] (if known)	Publication Date MM-DD-YYYY	Name of Patentee or Applicant of Cited Document	Pages, Columns Lines, Where Relevant Passages or Relevant Figures Appear
		US-			
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FOREIGN PATENT DOCUMENTS

Examiner Initials*	Cite No.[1]	Document Number (ctry[3]-no.[4]-kind[5], if known)	Publication Date MM-DD-YYYY	Name of Patentee or Applicant of cited document	Pages, Columns Lines, Where Relevant Passages or Relevant Figures Appear	T[6]
VL		WO 01 20912	03-22-2001	DROUOT, Antoine		

NON-PATENT LITERATURE DOCUMENTS

Examiner Initials*	Cite No.[1]	Include name of the author (in capital letters), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc.), date, page(s), volume-issue number(s), publisher, city and/or country where published.	T[6]

Examiner Signature	VU LE PRIMARY EXAMINER	Date Considered	1/11/05

		Application/Control No.	Applicant(s)/Patent Under Reexamination
Notice of References Cited		10/044,876	LIN ET AL.
		Examiner	Art Unit
		Vu Le	2613

U.S. PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Name	Classification
	A	US-6,266,102 B1	07-2001	Azuma et al.	348/671
	B	US-5,724,453	03-1998	Ratnakar et al.	382/251
	C	US-4,885,636	12-1989	Sullivan, James R.	375/240.14
	D	US-2001/0026283	10-2001	Yoshida et al.	345/600
	E	US-			
	F	US-			
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	H	US-			
	I	US-			
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	K	US-			
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	M	US-			

FOREIGN PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Country	Name	Classification
	N	EP0881837A1	02-1998	EP	Mancuso et al	H04N 7/30
	O					
	P					
	Q					
	R					
	S					
	T					

NON-PATENT DOCUMENTS

*		Include as applicable: Author, Title Date, Publisher, Edition or Volume, Pertinent Pages)
	U	Wu et al, "A Generalized Block-Edge Impairment Metric for Video Coding", IEEE Signal Processing Letters, vol. 4, no. 11, pp. 317-320, November 1997.
	V	
	W	
	X	

*A copy of this reference is not being furnished with this Office action. (See MPEP § 707.05(a).)
Dates in MM-YYYY format are publication dates. Classifications may be US or foreign.

A Generalized Block-Edge Impairment Metric for Video Coding

H. R. Wu and M. Yuen

Abstract— A new generalized block-edge impairment metric (GBIM) is presented in this paper as a quantitative distortion measure for blocking artifacts in digital video and image coding. This distortion measure does not require the original image sequence as a comparative reference, and is found to be consistent with subjective evaluation.

Index Terms—Blocking artifacts, quantitative impairment metric, video coding.

I. INTRODUCTION

FOR bit rates ranging from 64 kbps (ITU H.261) to as high as 10–12 Mbps (MPEG-2) [1], we have shown in [2] that blocking effects, and its propagation through reconstructed video sequences, are the most significant of all coding artifacts. The blocking effect is also a source of a number of other types of reconstruction artifacts, such as stationary area granular noise [3]. It is well known that many forms of quantitative quality metrics, or distortion measures, used in image and video coding research, such as mean squared error (MSE), peak signal-to-noise ratio (PSNR), and mean absolute error (MAE) [1], are ineffective in quantifying the visibility of reconstruction artifacts, and, therefore, are ill suited for evaluating image and video compression techniques and products. The reason for this relates to the fact that these measures do not necessarily reflect our visual perception of the coding distortions and artifacts found in reconstructed sequences. Consequently, there is a poor correlation between these metrics and subjective assessment [4].

Recently, Karunasekera and Kingsbury introduced a new distortion measure for blocking (edge) artifacts in compressed images based on human visual sensitivity [4]. This quantitative distortion measure requires both the original and reconstructed images to form an error image, which is then used as an input into their visual model. This approach is similar to most of the other existing quantitative distortion measures [5], [6]. In the absence of the original image, the above distortion measures cannot be used to evaluate the quality of a reconstructed image or the presence of coding artifacts, such as the blocking effect.
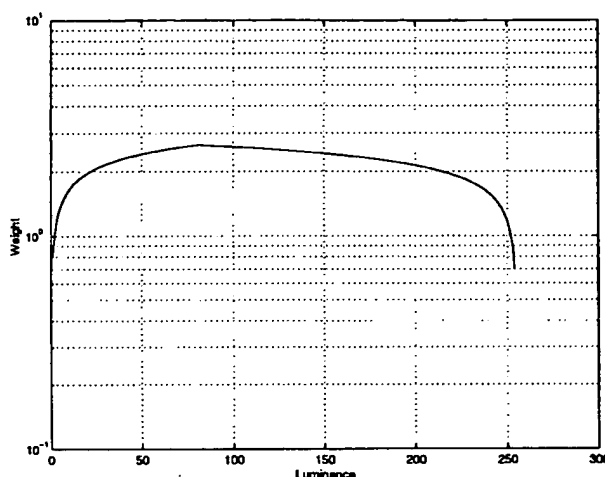
Fig. 1. The weighting function for the generalized BIM.

In [2], the block-edge impairment metric (BIM) was introduced to evaluate the visual significance of block-edge artifacts in a given image. The BIM was based on a formulation of constraint sets applied successfully in the postfiltering of reconstructed video images using projections onto convex sets (POCS) algorithms [7]. Whilst achieving results consistent with subjective evaluations, this metric was characterized by the fact that it did not require the original image to produce a measure of the distortion in a reconstructed image.

To take into account the luminance masking effects in extreme bright as well as extreme dark areas in a reconstructed image, a more general formulation of the BIM is presented in Section II of this contribution, parameters of which can be adjusted to correspond with the visibility of noise modeled in [8]. Section III will present experimental results using this generalized BIM as a distortion measure compared with PSNR.

II. A GENERALIZED BLOCK-EDGE IMPAIRMENT METRIC

In [8], Girod suggested that distortions are most noticeable where the luminance value is between 70 and 90 (centered approximately on 81) in 8-b grey-scale images. To accommodate this observation, and to maintain the simplicity of the weighting function in the BIM, a generalized BIM (GBIM) is formulated as follows.

Given an image $f = \{f_{c1}f_{c2}\cdots f_{cN_c}\}$, where f_{cj} is the jth column of the image array and N_c is the width of the image, we define the interpixel difference between each of the horizontal

Fig. 2. Reconstructed I picture from MPEG-1 coded mobile and calendar video sequence (0.8 Mbps, IBBBPBBBP$\cdots$). $M_{\text{GBIM}} = 3.11$ and PSNR $= 21.75$ dB.

block boundaries (vertical edge artifacts) by

$$D_c \mathbf{f} = \begin{bmatrix} \mathbf{f}_{c8} - \mathbf{f}_{c9} \\ \mathbf{f}_{c16} - \mathbf{f}_{c17} \\ \vdots \\ \mathbf{f}_{c(N_c-8)} - \mathbf{f}_{c(N_c-7)} \end{bmatrix} \quad (1)$$

where we assume 8×8-pel blocks, as commonly used in video coding standards.

A metric can be defined to measure the horizontal blockiness by

$$\begin{aligned} M_h &= \| \mathbf{W} D_c \mathbf{f} \| \\ &= \left[\sum_{k=1}^{N_c/8-1} \| \mathbf{w}_k [\mathbf{f}_{c(8 \times k)} - \mathbf{f}_{c(8 \times k+1)}] \|^2 \right]^{1/2} \quad (2) \end{aligned}$$

where $\| \cdot \|$ is the l_2 norm and $\mathbf{W} =$ diag[$\mathbf{w}_1, \mathbf{w}_2, \cdots, \mathbf{w}_{N_c/8-1}$] is a diagonal weighting matrix which takes into account the local spatial characteristics of a given image [7], [9]. Each $\mathbf{w}_k = $ diag[$w_{1,j}, w_{2,j}, \cdots, w_{N_r,j}$], where N_r is the height of the image, and $j = 8 \times k$ for $k = 1, 2, \cdots, N_c/8 - 1$. The weighting function for each block-edge pel difference

is given by

$$w_{i,j} = \begin{cases} \lambda \ln \left(1 + \dfrac{\sqrt{\mu_{i,j}}}{1 + \sigma_{i,j}} \right), & \text{if } \mu_{i,j} \leq \zeta \\ \ln \left(1 + \dfrac{\sqrt{255 - \mu_{i,j}}}{1 + \sigma_{i,j}} \right), & \text{otherwise} \end{cases} \quad (3)$$

at pel location (i, j), which accounts for the human visual system (HVS) masking of the block-edge artifacts in extreme bright and dark areas, as well as spatially busy areas, of an image [8]. In (3), ζ is the selected average luminance value for which the highest weight should be given to the distortion, and λ is calculated as

$$\lambda = \frac{\ln(1 + \sqrt{255 - \zeta})}{\ln(1 + \sqrt{\zeta})}. \quad (4)$$

The weighting function defined in (3) is shown in Fig. 1, assuming $\sigma_{i,j} = 0$ and $\zeta = 81$.

For horizontal block boundaries, the local mean $\mu_{i,j}$ in (3) is based on the mean of the pels within the two adjoining blocks of the current row as follows:

$$\mu_{i,j} = \frac{\mu_{i,j}^L + \mu_{i,j}^R}{2}$$

where $\mu_{i,j}^L$ and $\mu_{i,j}^R$ are the means of the pels within row i of the blocks to the left and right, respectively, of the current

Fig. 3. POCS filtered I picture reconstruction from MPEG-1 coded mobile and calendar video sequence (0.8 Mbps, IBBBPBBBP···). $M_{\mathrm{GBIM}} = 1.05$ and PSNR = 21.86 dB.

block boundary

$$\mu_{i,j}^{L} = \tfrac{1}{8} \sum_{n=j-7}^{j} f_{i,n}; \qquad \mu_{i,j}^{R} = \tfrac{1}{8} \sum_{n=j+1}^{j+8} f_{i,n}$$

where $f_{i,n}$ represents an individual pel located at row i and column n of picture f.

Similarly, the standard deviation $\sigma_{i,j}$ in (3) is given by

$$\sigma_{i,j} = \frac{\sigma_{i,j}^{L} + \sigma_{i,j}^{R}}{2}$$

where $\sigma_{i,j}^{L}$ and $\sigma_{i,j}^{R}$ are the standard deviations of the pels within row i of the blocks to the left and right, respectively, of the block boundary

$$\sigma_{i,j}^{L} = \left[\tfrac{1}{8} \sum_{n=j-7}^{j} (f_{i,n} - \mu_{i,j}^{L})^2 \right]^{1/2}$$

$$\sigma_{i,j}^{R} = \left[\tfrac{1}{8} \sum_{n=j+1}^{j+8} (f_{i,n} - \mu_{i,j}^{R})^2 \right]^{1/2}.$$

A similar procedure is used for calculating the weights for vertical block boundaries, with the only difference being that consideration is taken of the statistical characteristics of the columns, instead of the rows, of the abutting blocks above and below any given block boundary.

We further normalize M_h by the average interpixel difference, E, between pels which are not at block boundaries, resulting in $M_{h\mathrm{GBIM}} = M_h/E$. The formula to calculate E is defined as

$$E = \tfrac{1}{7} \sum_{n=1}^{7} S_n \tag{5}$$

where

$$S_n = \left[\sum_{k=1}^{N_c/8-1} \| \, \mathbf{w}_k [\mathbf{f}_{c(8 \times k+n)} - \mathbf{f}_{c(8 \times k+n+1)}] \, \|^2 \right]^{1/2}. \tag{6}$$

A metric $M_{v\mathrm{GBIM}}$ can be similarly defined to measure the blockiness across vertical block boundaries of reconstructed images. The generalized BIM for the analysis of image reconstruction quality is therefore given by

$$M_{\mathrm{GBIM}} = \alpha \, M_{h\mathrm{GBIM}} + \beta \, M_{v\mathrm{GBIM}}. \tag{7}$$

The higher the M_{GBIM} value is above one, the greater the severity of the blocking effect. The two parameters, λ and ζ, in (3) can be adjusted to provide a better correlation between this metric and subjective assessment of the distortion.

TABLE I
PSNR AND M_{GBIM} VALUES OF RECONSTRUCTED I-FRAMES
BEFORE AND AFTER POCS FILTERING FOR THE BLOCKING EFFECT

Sequence	Bitrate (Mbps)	Unfiltered		Filtered	
		M_{GBIM}	PSNR	M_{GBIM}	PSNR
Claire	0.4	4.09	36.46	1.19	37.30
	0.6	2.24	41.36	1.24	41.70
	0.8	1.80	45.26	1.30	45.29
Flower garden	0.4	3.46	21.31	1.09	21.49
	0.6	2.34	22.30	1.10	22.48
	0.8	1.85	23.85	1.10	24.04
Football	0.4	2.91	28.38	1.03	28.57
	0.6	2.02	30.02	1.03	30.18
	0.8	1.71	31.44	1.03	31.60
Mobile & calendar	0.4	4.42	20.91	1.06	21.04
	0.6	3.61	21.38	1.05	21.51
	0.8	3.11	21.75	1.05	21.86
PRL car	0.4	4.06	28.35	1.06	28.62
	0.6	2.60	30.45	1.10	30.69
	0.8	2.17	32.06	1.12	32.29
Table-tennis	0.4	2.68	25.30	1.06	25.35
	0.6	1.90	26.16	1.04	26.19
	0.8	1.48	27.31	1.03	27.33

III. SIMULATION RESULTS

In our experiments, we used CIF-sized images (352 × 288) and assumed that the human sensitivity to horizontal and vertical blocking artifacts are similar [4], and therefore selected $\alpha = \beta = 0.5$ in (7). The subjective evaluation was conducted using an Abekas A65 Digital Disk Recorder with a Sony PVM-2130QM Color Video Monitor.

A reconstructed I picture of the mobile and calendar sequence (MPEG-1 coded at 0.8 Mbps) is shown with its M_{GBIM} and PSNR values in Fig. 2, compared with a POCS filtered [9] reconstruction of the same picture, also shown with its M_{GBIM} and PSNR values, in Fig. 3. These experiments demonstrate that the POCS filtering reduces the blocking artifacts significantly, and also shows that M_{GBIM} is a very effective measure for blocking artifacts in terms of consistency with subjective evaluations. It is interesting to note that the reconstructed picture has $M_{h\text{GBIM}} = 3.29$ and $M_{v\text{GBIM}} = 2.95$, respectively, indicating that the horizontal blockiness

(or vertical edge artifacts) is more prominent than the vertical blockiness (or horizontal edge artifacts). The POCS filtered reconstruction of the same picture has $M_{h\text{GBIM}} = M_{v\text{GBIM}} = 1.05$. The values obtained using M_{GBIM} are found to be consistent with subjective evaluations. Similar results were also obtained for several other MPEG-1 coded sequences, at various bitrates. Table I provides a compilation of the PSNR and M_{GBIM} values for these sequences. Due to space restrictions, the corresponding reconstructed images are not shown here.

IV. CONCLUSIONS

This letter introduced a generalized block-edge impairment metric that enables the evaluation of reconstructed picture quality without the need for the original images as comparative references. This work has shown that the evaluation of blocking artifacts using this metric is very effective and consistent with subjective evaluation.

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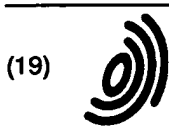
(12) **EUROPEAN PATENT APPLICATION**

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(54) **Post-processing method for reducing artifacts in block-coded digital images, and post-processing device for actuating such method**

(57) A post-processing method for reducing artifacts in block-coded digital images, characterized by providing for: dividing an input image (In) into a plurality of image blocks (IB); for each image block (IB), estimating global features (GF) of said image block providing information on an average content of image edges along the horizontal and vertical directions of said image block (IB); for each pixel (Px) of an image block (IB) under examination, estimating local features (LF) for said pixel (Px) providing information on the content of image edges along the horizontal and vertical directions of an image area near said pixel (Px); modifying the value of said pixel (Px) according to both said global features (GF) of the image block (IB) to which said pixel (Px) belongs and said local features (LF) of the image area near said pixel (Px).

Fig.1
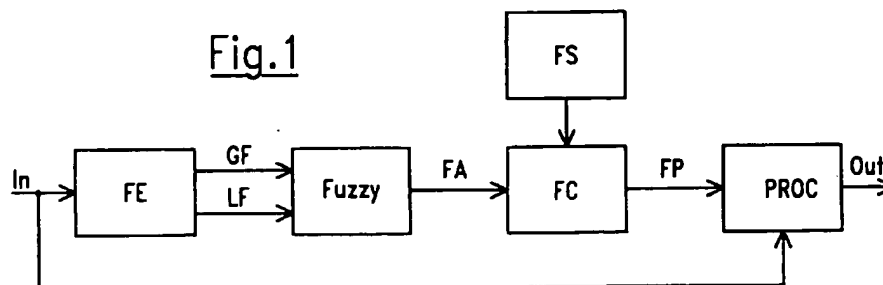
Description

The present invention relates digital image coding. More precisely, the invention relates to a post-processing method for reducing artifacts in block-coded digital images, and to a post-processing device suitable for actuating such a method.

With the diffusion of digital communication systems, digital images are more and more used. This has led to the diffusion of still and video cameras with digital acquisition and processing capability.

In order to better exploit storage means and transmission bandwidth, digital image compression standards have been developed, such as JPEG for still images, and MPEG-1 and MPEG-2 for digital television image sequences.

The above-referred compression standards provides for block-coding based on Discrete Cosine Transform (DCT). A digital image is divided into blocks of pixels, and each block is encoded independently from the others. DCT coefficients for the pixels of each block are evaluated and a quantization matrix is applied to the DCT coefficients to reduce the information to be stored or transmitted. When the image is to be displayed, it must be decoded in advance.

Due to the quantization process, these image compression methods are lossy, i.e. they cause a loss of information in the decoded image with respect to the original image. The decoded image can thus present noticeable degradation, mainly consisting of two kinds of artifacts known in the art under the names of "grid noise" and "staircase noise".

In order to reduce the image degradation, post-processing methods of the decoded image have been proposed which allow for attenuating grid noise and staircase noise.

In view of the state of the art described, it is an object of the present invention to provide a new post-processing method for reducing artifacts in block-coded digital images.

According to the present invention, such object is attained by means of a post-processing method for reducing artifacts in block-coded digital images, characterized by providing for:

a) dividing an input image into a plurality of image blocks;

b) for each image block, estimating global features of said image block providing information on an average content of image edges along the horizontal and vertical directions of said image block;

c) for each pixel of an image block under examination, estimating local features for said pixel providing information on the content of image edges along the horizontal and vertical directions of an image area around said pixel;

d) modifying the value of said pixel according to both said global features of the image block to which said pixel belongs and said local features of the image area around said pixel.

Also according to the invention, there is also provided a post-processing device for actuating said method, characterized by comprising:

- first means supplied with an input image for estimating global features of an image block under examination, said global features providing information on an average content of image edges along the horizontal and vertical directions of said image block;

- second means supplied with said input image for estimating local features for each pixel of the image block under examination, said local features providing information on the content of image edges along the horizontal and vertical directions of an image area around said pixel;

- third means supplied with said global features and said local features for modifying the value of said pixel according to both said global features and said local features.

The features and advantages of the present invention will be made apparent from the following detailed description of an embodiment thereof, illustrated as a non-limiting example in the annexed drawings, wherein:

Figure 1 is a schematic block diagram illustrating the principle of operation of a method according to the present invention;

Figure 2 shows a digital image divided into image blocks;

Figure 3 shows in detail an image block into which the digital image of Figure 2 is divided;

Figure 4 shows an array of pixels of the image block of Figure 3;

Figure 5 shows an image sub-block of the image block of Figure 3 used for evaluating global features of the image block;

Figure 6 shows an horizontal processing window used for evaluating local features in the horizontal direction for a generic pixel of the image block;

Figure 7 shows a vertical processing window used for evaluating local features in the vertical direction for said generic pixel;

Figures 8 and 9 shows two membership functions used to perform a fuzzy computation;

Figure 10 is a block diagram of a device according to the present invention;

Figure 11 shows the structure of two blocks of the device of Figure 10; and

Figure 12 is a block diagram of other two blocks of the device of Figure 10.

5   With reference to Figure 1, there is shown a block diagram illustrating the principle of operation of the post-process-
ing method according to the present invention. An input decoded compressed digital image In is supplied to a Feature
Extraction block FE. Block FE provides for analyzing the image to evaluate global and local features thereof. The global
and local features, respectively GF and LF, of the image In evaluated by block FE are supplied as inputs to a Fuzzy
Process block FUZZY which, according to fuzzy rules, determines parameters FA suitable for determining the kind of
10   filtering to be performed, in accordance to the global and local features GF and FL of the image. The parameters FA
calculated by block FUZZY are supplied to a Filter Composition block FC which according to said parameters FA deter-
mines the type of filtering to performed out of a set of predefined filters (block FS). Filter parameters FP determined by
block FC are then supplied to a Processing block PROC, also supplied directly with the input image In, which performs
the filtering of the input image In according to the filter parameters FP to provide a post-processed output image Out.
15   It appears that the kind of filtering to be performed on the decoded input image In is chosen after an estimation of
the global and local features of the decoded input image. For image areas near grid noise and near an edge, a low-pass
filtering is performed, to reduce both staircase noise and grid noise. For areas containing fine details (image edges and
texture), no filtering is performed. Thus, the method according to the present invention provides for performing a non-
linear adaptive filtering on the pixels of the decoded image.
20   The principle of operation outlined above will be now described in detail.

As shown in Figure 2, the input image In is partitioned into image blocks IB, each containing an equal number of
pixels. A typical dimension of the blocks is 8*8 pixels (Figure 3), but this is not however to be intended as a limitation,
since other block dimensions are suitable.

The image blocks IB of the input image In are scanned line by line starting from the top-left block to the bottom-right
25   one. For each image block IB, the Feature Extraction block FE in Figure 1 determines the global and local features GF
and LF.

Global features of the image block IB under examination are determined by applying horizontal and vertical Sobel
operators:

30
$$\text{horizontal Sobel operator (Hsob):} \begin{bmatrix} h11 & h12 & h13 \\ h21 & h22 & h33 \\ h31 & h32 & h33 \end{bmatrix};$$

35
$$\text{vertical Sobel operator (Vsob):} \begin{bmatrix} v11 & v12 & v13 \\ v21 & v22 & v23 \\ v31 & v32 & v33 \end{bmatrix}$$

40   to each pixel belonging to an image sub-block internal to the image block IB. For example, the following Sobel opera-
tors:

45
$$\text{Hsob:} \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix};$$

50
$$\text{Vsob:} \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix}$$

are applied to a 6*6 pixel image sub-block ISB (gray area in Figure 5). As shown in Figure 4, for each pixel Pi of the
image sub-block ISB a 3*3 array of neighboring pixels M centered in pixel Pi is considered, and the values of the pixels
55   of said array M are multiplied by the coefficients of the horizontal and vertical Sobel operators, to obtain:

$$\text{Hsob} = (P3+P8+2*P5) - (P1+P6+2*P4),$$

$$Vsob = (P6+P8+2^*P7) - (P1+P3+2^*P2),$$

where P1-P4 and P5-P8 are the values of the pixels (gray levels).

As known, horizontal and vertical Sobel operators perform a filtering capable of detecting edges along the horizon-
5 tal and vertical direction, respectively.

The output values of the horizontal Sobel operators calculated for the pixels of image sub-block ISB are accumu-
lated to obtain an accumulated value Acc(Hsob), and the output values of the vertical Sobel operators calculated for the
pixels of image sub-block ISB are accumulated to obtain an accumulated value Acc(Vsob). Acc(Hsob) gives the high-
frequency content in the horizontal direction (vertical edges) of the image block IB. Acc(Vsob) gives the high-frequency
10 content in the vertical direction (horizontal edges) of image block IB. Thus, Acc(Hsob) and Acc(Vsob) respectively pro-
vide the degree of "edgeness" of the image block under examination in the vertical and horizontal directions. It is to be
noted that in order to evaluate the global features GF of the image block IB under examination, only the pixels belonging
to this block are considered (by applying 3*3 Sobel operators to the 6*6 image sub-block ISB, it is not necessary to take
into consideration pixels belonging to neighboring image blocks).
15 Global features GF of the image block under examination can be formed by the accumulated values Acc(Hsob) and
Acc(Vsob). Alternatively, the global features GF of the image block can be formed by an average of the accumulated
values Acc(Hsob) and Acc(Vsob), to obtain the average number of edges in the horizontal and vertical directions in the
image block under examination.

Local features LF of the image block IB are estimated according to the following method. All the pixels of the image
20 block IB under examination are scanned line by line starting from the top-left pixel down to the bottom-right one. To each
pixel a horizontal processing window is applied: a prescribed number of pixels respectively preceding and following the
pixel under consideration and belonging to the same image line of the pixel under consideration is considered. A suita-
ble horizontal processing window HPW is shown in Figure 6, which is a horizontal 1*5 processing window: for a given
pixel, the two preceding pixels Pa, Pb and the two following pixels Pc, Pd belonging to the same line are considered. In
25 Figure 6 there is shown by way of example the horizontal processing window HPW associated to the first pixel Px of the
image block. It should be noted that not only the pixels of the image block IB under examination are considered, but also
pixels belonging to neighboring image blocks; this is for example the case of the first, second, seventh and eight pixel
of each line of pixels of the image block IB under examination.

The horizontal Sobel operator Hsob previously mentioned is applied to each pixel Pa, Pb, Px, Pc, Pd in the horizon-
30 tal processing window HPW, to obtain five output values HS1-HS5. Values HS1-HS5 provide the local features in the
horizontal direction for the pixel under examination Px, i.e. the high-frequency content in the horizontal direction of the
image region around the pixel under examination.

Similarly, a vertical processing window is applied to each pixel of the image block IB. The vertical processing win-
dow is formed by the pixel under consideration Px, and a prescribed number of pixels belonging to the same column as
35 and preceding and following the pixel under consideration; for example, as shown in Figure 7 the vertical processing
window VPW can have dimensions identical to the horizontal processing window HPW (5*1), and thus contains two pix-
els Pe, Pf preceding pixel Px and two pixels Pg, Ph following pixel Px in the vertical direction.

The vertical Sobel operator Vsob previously mentioned is then applied to each pixel of the vertical processing win-
dow VPW to obtain five output values VS1-VS5. Values VS1-VS5 form the local features in the vertical direction for the
40 pixel under examination, i.e. the high-frequency content in the vertical direction of an image region around the pixel
under examination.

The global features GF for the image block IB under examination (i.e., the two accumulated values Acc(Hsob) and
Acc(Vsob) or, in alternative, the average value of Acc(Hsob) and Acc(Vsob)) and the local features LF for the pixel
under examination inside said image block (the ten values HS1-HS5 and VS1-VS5) are then supplied to the Fuzzy
45 Process block FUZZY. This block provides for evaluating the degree of membership of a generic value HSi and Vsi
(i=1..5) to two fuzzy sets "Small" and "Big"; these degree of membership can be evaluated by applying to HSi, VSi the
membership functions depicted in Figures 8 and 9. In these figures, Th1 and Th2 are values depending on the global
features GF of the image block under examination, i.e. on the accumulated values Acc(Hsob) and Acc(Vsob) or on the
average of the accumulated values; in the first case, Th1 and Th2 are different for the Hsi and Vsi values; in the second
50 case, Th1 and Th2 are the same for Hsi and Vsi values.

Fuzzy rules having as antecedents the degrees of membership of the output values HSi and VSi to the two fuzzy
sets "Small" and "Big" are then evaluated. This means that 32 rules are to be evaluated for both the horizontal and ver-
tical directions. However, all those fuzzy rules having the same consequence are synthesized in one rule only by an else
operator. In this way, the system complexity is reduced, and a total of nine rules for each direction have to be evaluated.
55 The following fuzzy rules are applied to the five values HS1-HS5 associated to the horizontal direction:

1. *If HS1 is* Small *and HS2 is* Small *and HS3 is* Small *and HS4 is* Small *and HS5 is* Small, *then* α1 *is* Big;
2. *If HS1 is* Small *and HS2 is* Small *and HS3 is* Small *and HS4 is* Small *and HS5 is* Big, *then* α2 *is* Big;

3. *If HS1 is Small and HS2 is Small and HS3 is Small and HS4 is Big and HS5 is Small, then* $\alpha 3$ *is Big;*

4. *If HS1 is Small and HS2 is Small and HS3 is Small and HS4 is Big and HS5 is Big, then* $\alpha 4$ *is Big;*

5. *If HS1 is Small and HS2 is Big and HS3 is Small and HS4 is Small and HS5 is Small, then* $\alpha 5$ *is Big;*

6. *If HS1 is Big and HS2 is Small and HS3 is Small and HS4 is Small and HS5 is Small, then* $\alpha 6$ *is Big;*

7. *If HS1 is Big and HS2 is Small and HS3 is Small and HS4 is Small and HS5 is Big, then* $\alpha 7$ *is Big;*

8. *If HS1 is Big and HS2 is Big and HS3 is Small and HS4 is Small and HS5 is Small, then* $\alpha 8$ *is Big.*

The activation level of each rule depends on the degree of memberships of the pattern of output values HSi of the horizontal Sobel operator applied to the five pixels of the horizontal processing window HPW; the degree of memberships depend in turn on the global features GF of the image block to which the pixel under examination belongs. The activation level of the else (ninth) rule is computed as αelse $= (1 - \alpha$ave$)$, where αave is the average activation degree of fuzzy rules 1 to 8. $\alpha 1$ to $\alpha 8$ and αelse, and a similar set of nine activation degrees for the fuzzy rules applied to values VS1-VS5) form the output FA of the fuzzy process block FUZZY in Figure 1.

Each one of the above-listed rules is associated to a respective set of predefined filter parameters, which are stored as a look-up table in block FS of Figure 1. Suitable predefined filter parameter sets are for example:

Rule 1: (c11=1.0, c12=1.0, c13=1.0, c14=1.0, c15=1.0) if the pixel under examination lies outside the image sub-block ISB, and (c11=0.0, c12=1.0, c13=1.0, c14=1.0, c15=0.0) if the pixel under examination lies inside the image sub-block ISB;

Rule 2: (c21=0.5, c22=1.0, c23=1.0, c24=1.0, c25=0.0);

Rule 3: (c31=0.5, c32=1.0, c33=1.0, c34=0.0, c35=0.0);

Rule 4: (c41=0.5, c42=1.0, c43=1.0, c44=0.0, c45=0.0);

Rule 5: (c51=0.0, c52=0.0, c53=1.0, c54=1.0, c55=0.5);

Rule 6: (c61=0.0, c62=1.0, c63=1.0, c64=1.0, c65=0.5);

Rule 7: (c71=0.0, c72=1.0, c73=1.0, c74=1.0, c75=0.0);

Rule 8: (c81=0.0, c82=0.0, c83=1.0, c84=1.0, c85=0.5);

Else rule: (c91=0.0, c92=0.0, c93=1.0, c94=0.0, c95=0.0).

The parameters FP of the filter to be applied to the five pixels of the horizontal processing window HPW are calculated as a weighted average of the nine filters described above, with weight factors formed by the activation degrees $\alpha 1$ to $\alpha 8$ and αelse of the respective fuzzy rules.

Assuming that αi is the activation degree of the i-th fuzzy rule (i=1..9), the ninth fuzzy rule being the else fuzzy rule $(\alpha 9 = \alpha$else$)$, and cij are the coefficients of the i-th filter (i=1..9, j=1..5), the weight factor applied to the i-th filter, associated to the i-th fuzzy rule is:

$$F_i = \alpha i \cdot c_{ij}$$

and the coefficients Hj of the final horizontal filter to be applied to the pixels of the horizontal processing window HPW are given by:

$$H_j = \frac{\sum_{i=1}^{9} \alpha i \cdot c_{ij}}{N}$$

where N is a normalization factor.

The horizontally-filtered value $\underline{Px}$ of the pixel Px under examination (at the center of the horizontal processing window) is then calculated as a weighted average of the values of the pixels Pa, Pb, Px, Pc and Pd belonging to the horizontal processing window HPW, with weight factors formed by the coefficients Hj:

$$\underline{Px} = H1^*Pa + H2^*Pb + H3^*Px + H4^*Pc + H5^*Pd.$$

Similar calculations are performed for the vertical direction, starting from the output values VS1-VS5 of the vertical Sobel operators applied to the pixels Pe, Pf, Px, Pg and Ph in the vertical processing window VPW. The coefficients Vj (j=1..5) of the filter for the vertical direction are calculated in a way completely similar to that used for determining the coefficients Hj:

$$V_j = \frac{\sum_{i=1}^{9} \beta_i \cdot c_{ij}}{N}$$

where β_i (i=1..9) are the activation degrees of nine fuzzy rules for the vertical direction (similar to those listed above for the horizontal direction) and c_{ij} (j=1..5) now are the predefined filter parameters associated to the i-th fuzzy rule for the vertical direction. The coefficients V_j are then applied to the pixels in the vertical processing window VPW to calculate a weighted average of the same. The filtered value of the pixel Px under examination, filtered in both the horizontal and vertical direction, is provided at the output Out of the processing block PROC.

The value of the pixel Px under examination to be multiplied by the vertical filter coefficient V3 can be the value P̲x obtained after having applied to the pixels in the horizontal processing window HPW the horizontal filter Hj (j=1..5):

$$Out = V1^*Pe + V2^*Pf + V3^*\underline{Px} + V4^*Pg + V5^*Ph.$$

Alternatively, it is possible to evaluate first the vertically-filtered value P̲x of the pixel under examination:

$$Px̲ = V1^*Pe + V2^*Pf + V3^*Px + V4^*Pg + V5^*Ph,$$

and then performing the filtering in the horizontal direction applying to this value the respective coefficient H3 of the horizontal filter Hj:

$$Out = H1^*Pa + H2^*Pb + H3^*\underline{Px} + H4^*Pc + H5^*Pd.$$

The sequence is of no importance, the important thing to be underlined being that at the end of the process the value of the pixel under examination is the result of both an horizontal and a vertical filtering.

Figure 10 is a block diagram of a device suitable for actuating the method previously described. The device comprises two main blocks: a first block 1 evaluates the global features GF of the image blocks IB the image to be post-processed is divided in, and a second block 2 evaluates the local features LF of the pixels of the image and performs the filtering according to both the global features and the local features.

It is assumed that the image to be post-processed is scanned line by line in a sequential order. Signal In is a stream of pixels of the input image scanned line by line. Block 1 is supplied with signal In; signal In also supplies a cascade of two line memories LM1 and LM2 whose outputs supplies block 1.

Inside block 1, signal In and the outputs of line memories LM1 and LM2 supply a block 3 of pixel delays suitable for implementing a 3*3 pixel window which is used to calculate horizontal and vertical Sobel operators for the pixels of the 6*6 image sub-block ISB inside each image block IB. Block 3 supplies a block 4 which calculates the outputs Hsob and Vsob of the horizontal and vertical Sobel operators for those pixels of the current image line belonging to the 6*6 image sub-blocks ISB of each image block IB. The outputs Hsob and Vsob of block 4 are supplied to an accumulator block 5 wherein they are accumulated. After eight image lines, i.e. a line of image blocks IB, have been scanned, the accumulated values Acc(Hsob), Acc(Vsob) (or alternatively the average thereof) for each image block IB are stored in a memory block 6.

The output of line memory LM2 supplies a cascade of eight further line memories LM3-LM10. Block 2 is supplied in parallel with the outputs of line memories LM4-LM10. In this way, evaluation of the local features and calculation of the filter parameters starts after block 1 has estimated the global features GF for a line of image blocks IB.

Inside block 2, a block 7 of pixel delays is supplied with the outputs of line memories LM4-LM10; by means of the line memories LM4-LM10 and the pixel delay block 7 it is possibile to implement the 5*1 vertical processing window VPW. The outputs L4-L10 of the pixel delays block 7 supply a block 8 which applies the vertical Sobel operator to each pixel inside the vertical processing window VPW. To avoid the use of further line memories, a parallel approach is preferred providing for calculating five vertical Sobel operators in parallel; the outputs of the five vertical Sobel operators VS1-VS5 are supplied to a vertical fuzzy filter 9, which is also supplied with the outputs L6-L10 of the pixel delay block 7 and the output MOUT of the memory MEM of block 1. MOUT supplies the global features GF of the image block IB currently processed by block 2, i.e. the accumulated value Acc(Vsob) or, alternatively, the average of Acc(Vsob) and Acc(Hsob). The vertical fuzzy filter block 9 evaluates the degree of membership of values VS1-VS5 to the fuzzy sets "Small" and "Big" taking into account the global features provided by MOUT, evaluates the activation levels of the nine fuzzy rules for the vertical direction, calculates the coefficients Vj (j=1..5) of the vertical filter and applies the vertical filter coefficients Vj to the five pixels Pe, Pf, Px, Pg, Ph in the vertical processing window VPW, to calculate the vertically-filtered value P̲x of the pixel in the middle of the vertical processing window. The output of the vertical fuzzy filter block 9 forms the vertically-filtered value P̲d of pixel Pd in the horizontal processing window HPW shown in Figure 6 and sup-

plies directly a horizontal fuzzy filter block 10; the output Pd of block 9 also supplies a cascade of four pixel delays D whose outputs respectively form the vertically-filtered values Pc, Px, Pb, Pa of the pixels Pc, Px, Pb, Pa in the horizontal processing window HPW and supply the horizontal fuzzy filter block 10.

In parallel to blocks 8 and 9, the outputs L7-L9 of the pixel delay block 7 supply a block 11 which applies the hori-
5   zontal Sobel operators to the pixels inside the horizontal processing window HPW. Differently from the vertical sobel operators, only one horizontal sobel operator is calculated at a time; a compensation delay block 12 introduces a delay for compensating the processing delay of the vertical fuzzy filter block 9. The output of block 12, forming the output of the horizontal Sobel operator HS5 applied to pixel Pd of the horizontal processing window in Figure 6, supplies the horizontal fuzzy filter block 10 and a cascade of four pixel delays D, the outputs thereof forming the values HS4, HS3, HS2
10   and HS1 and suppling the horizontal fuzzy filter block 10. The horizontal fuzzy filter block 10, which is also supplied by the output MOUT of the memory block MEM in block 1 providing the value Acc(Hsob) (or alternatively the average of values Acc(Hsob) and Acc(Vsob)), evaluates the degree of membership of values HS1-HS5 to the fuzzy sets "Small" and "Big" according to the value of the global features GF provided by MOUT, evaluates the activation levels of the nine fuzzy rules described above for the filtering in the horizontal direction, calculates the coefficients Hj of the horizontal fil-
15   ter and applies the parameters Hj to the vertically-filtered values Pa, Pb, Px, Pc, Pd of the pixels Pa, Pb, Px, Pc, Pd in the horizontal processing window HPW to obtain the horizontally- and vertically-filtered value Out of the pixel Px under examination.

A control circuit CTRL controls the operation of blocks 1, 2 and the line memories LM1-LM10.

Figure 11 shows the structure of the vertical and horizontal Sobel operator blocks 8 and 11 of Figure 10. They are
20   composed in a straightforward way by adders.

Figure 12 shows the structure of both the vertical fuzzy filter block 9 and the horizontal fuzzy filter block 10. X1-X5 are the vertical or, respectively, horizontal Sobel operator outputs VS1-VS5 and HS1-HS5. X1-X5 are supplied to a fuzzy rule evaluation block 13 which evaluates the activation degrees β1-β9 of the nine fuzzy rules for the vertical direction or, respectively, the activation degrees α1-α9 of the nine fuzzy rules for the horizontal direction. The activation
25   degrees evaluated by block 13 are supplied to a look-up table of respective predefined filter parameters F1-F9 (forming block FS in Figure 1), and the outputs of the look-up table, i.e. the predefined filter parameters cij multiplied by the activation degree of the respective fuzzy rule, are supplied to a filter composition block 14 which calculates the coefficients V1-V5 or, respectively, H1-H5, of the vertical or, respectively, horizontal filter. Said coefficients are then supplied to a processing block 15 which is also supplied with the pixel values PXS (L6-L10 or, respectively, Pa, Pb, Px, Pc, Pd in Fig-
30   ure 10); block 15 applies the filter coefficients to the pixel values to obtain the filtered value of the pixel under examination Px.

Claims

35   1.   Post-processing method for reducing artifacts in block-coded digital images, characterized by providing for:

a) dividing an input image (In) into a plurality of image blocks (IB);
b) for each image block (IB), estimating global features (GF) of said image block providing information on an average content of image edges along the horizontal and vertical directions of said image block (IB);
40   c) for each pixel (Px) of an image block (IB) under examination, estimating local features (LF) for said pixel (Px) providing information on the content of image edges along the horizontal and vertical directions of an image area near said pixel (Px);
d) modifying the value of said pixel (Px) according to both said global features (GF) of the image block (IB) to which said pixel (Px) belongs and said local features (LF) of the image area near said pixel (Px).

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2.   Method according to claim 1, characterized in that step d) provides for:

d1) defining a set of predefined local features;
d2) determining degrees of coincidence (α1-α9,β1-β9)of said local features (LF) of the image area around said
50   pixel (Px) with each predefined local features of said set, said degrees of coincidence (α1-α9,β1-β9) depending on said global features (GF) of the image block (IB) to which said pixel (Px) belongs;
d3) making the value of said pixel (Px) equal to a weighted average (Px,Px) of the value of said pixel (Px) and of the values of neighboring pixels (Pa-Pd,Pe-Pf), with weight factors (H1-H5,V1-V5) depending on said degrees of coincidence of said local features (LF) with each of said predefined local features.

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3.   Method according to claim 2, characterized in that said determining the degrees of coincidence (α1-α9,β1-β9) in step d2) provides for performing a fuzzy calculation.

4. Method according to claim 3, characterized in that each of said predefined local features is associated to a respective group of predefined weight factors (cij), and each of said weight factors (H1-H5,V1-V5) is calculated as a weighted average of corresponding predefined weight factors (cij) of said groups with weight coefficients ($\alpha1$-$\alpha9$,$\beta1$-$\beta9$) depending on said degrees of coincidence of said local features (LF) with each of said predefined local features.

5. Method according to claim 4, characterized in that said estimating global features (GF) of the image block (IB) under examination provides for applying horizontal and vertical Sobel operators (Hsob,Vsob) to pixels belonging to an image sub-block (ISB) internal to said image block (IB) under examination.

6. Method according to claim 5, characterized in that said estimating global features (GF) of the image block (IB) under examination provides for adding outputs of the horizontal Sobel operators (Hsob) applied to each pixel of said image sub-block (ISB) to obtain an accumulated output of horizontal Sobel operators (Acc(Hsob)), and adding outputs of the vertical Sobel operators (Vsob) applied to each pixel of said image sub-block (ISB) to obtain an accumulated output of vertical Sobel operators (Acc(Vsob)).

7. Method according to claim 6, characterized in that said global features (GF) of the image block (IB) under examination are formed by said accumulated outputs of the horizontal and vertical Sobel operators (Acc(Hsob),Acc(Vsob)).

8. Method according to claim 6, characterized in that said global features (GF) of the image block (IB) under examination are formed by an average of said accumulated outputs of the horizontal and vertical Sobel operators (Acc(Hsob),Acc(Vsob)).

9. Method according to claim 7 or 8, characterized in that said estimating local features (LF) for a pixel (Px) of the image block (IB) under examination provides for:

c1) considering an horizontal processing window (HPW) containing the pixel (Px) under examination and neighboring pixels (Pa,Pb,Pc,Pd) belonging to a same image line as the pixel (Px) and preceding and following the pixel (Px);
c2) applying said horizontal Sobel operator (Hsob) to each pixel (Pa-Pd,Px) of the horizontal processing window (HPW) to obtain a horizontal pattern of horizontal Sobel operator outputs (HS1-HS5);
c3) considering a vertical processing window (VPW) containing the pixel (Px) under examination and neighboring pixels (Pe,Pf,Pg,Ph) belonging to a same column of pixels as the pixel (Px) and preceding and following the pixel (Px);
c4) applying said vertical Sobel operator (Vsob) to each pixel (Pe-Ph,Px) of the vertical processing window (VPW) to obtain a vertical pattern of vertical Sobel operator outputs (VS1-VS5).

10. Method according to claim 9, characterized in that said horizontal and vertical processing windows (HPW,VPW) contains each one five pixels and are centered at said pixel (Px) under examination.

11. Method according to claim 10, characterized in that step d2) provides for determining degrees of membership of each horizontal Sobel operator output (HS1-HS5) of the horizontal pattern to a first fuzzy set "Small" and to a first fuzzy set "Big", evaluating activation degrees ($\alpha1$-$\alpha9$) of a first set of fuzzy rules each one associated with at least one predefined horizontal pattern of horizontal Sobel operator outputs, determining degrees of membership of each vertical Sobel operator output (VS1-VS5) of the vertical pattern to a second fuzzy set "Small" and to a second fuzzy set "Big" and evaluating activation degrees ($\beta1$-$\beta9$) of a second set of fuzzy rules each one associated with at least one predefined vertical pattern of vertical Sobel operator outputs.

12. Method according to claim 11, characterized in that said determining degrees of membership of the horizontal Sobel operator outputs (HS1-HS5) of the horizontal pattern to said first fuzzy sets "Small" and "Big" provides for determining a first and a second membership functions depending on said global features (GF), and said determining degrees of membership of the vertical Sobel operator outputs (VS1-VS5) of the vertical pattern to said second fuzzy sets "Small" and "Big" provides for determining a third and fourth membership functions depending on said global features (GF).

13. Method according to claim 12, characterized in that said groups of predefined weight factors (cij) comprise groups of predefined horizontal weight factors and groups of predefined vertical weight factors, each fuzzy rule of said first

set being associated with a respective one of said groups of predefined horizontal weight factors, and each fuzzy rule of said second set being associated with a respective one of said groups of predefined vertical weight factors.

14. Method according to claim 13, characterized in that said weight factors (H1-H5,V1-V5) comprise horizontal weight factors (H1-H5) and vertical weight factors (V1-V5), said horizontal weight factors (H1-H5) being determined by making a weighted average of the predefined horizontal weight factors with weight coefficients being formed by the activation degrees (α1-α9) of the fuzzy rules of the first set, and said vertical weight factors (V1-V5) being determined by making a weighted average of the predefined vertical weight factors with weight coefficients formed by the activation degrees (β1-β9) of the fuzzy rules of the second set.

15. Method according to claim 14, characterized in that the value of the pixel (Px) under examination is modified by applying the horizontal weight factors (H1-H5) to the values of the pixels (Pa-Pd,Px) in the horizontal processing window (HPW) and applying the vertical weight factors (V1-V5) to the values of the pixels (Pe-Ph,Px) in the vertical processing window (VPW).

16. Post-processing device for reducing artifacts in block-coded digital images, characterized by comprising:

- first means (1) supplied with an input image (In) for estimating global features (MOUT) of an image block (IB) under examination, said global features providing information on an average content of image edges along the horizontal and vertical directions of said image block (IB);
- second means (7,8,11,12,D) supplied with said input image (In) for estimating local features (VS1-VS5,HS1-HS5) for each pixel (Px) of the image block (IB) under examination, said local features providing information on the content of image edges along the horizontal and vertical directions of an image area around said pixel (Px);
- third means (9,D,10) supplied with said global features (MOUT) and said local features (VS1-VS5,HS1-HS5) for modifying the value of said pixel (Px) according to both said global features (MOUT) and said local features (VS1-VS5,HS1-HS5).

17. Device according to claim 16, characterized in that said first means (1) comprises means (3,4) for evaluating horizontal and vertical Sobel operator outputs (Hsob,Vsob) of horizontal and vertical Sobel operators applied to pixels of an image sub-block (ISB) internal to said image block (IB) under examination, and accumulator means (5) for accumulating the horizontal Sobel operator outputs (Hsob) and the vertical Sobel operator outputs (Vsob) for each pixel of the image sub-block (ISB).

18. Device according to claim 17, characterized in that said second means (7,8,11,12,D) comprises fourth means (7,8) for evaluating vertical Sobel operator outputs (VS1-VS5) of vertical Sobel operators (Vsob) applied to said pixel (Px) and to vertically-neighboring pixels (Pe,Pf,Pg,Ph) preceding and following the pixel (Px) in the vertical direction, and fifth means (11,12,D) for evaluating horizontal Sobel operator outputs (HS1-HS5) of horizontal Sobel operators (Hsob) applied to said pixel (Px) and to horizontally-neighboring pixels (Pa,Pb,Pc,Pd) preceding and following the pixel (Px) in the horizontal direction.

19. Device according to claim 18, characterized in that said third means (9,D,10) comprises vertical filter means (9,D) supplied with said vertical Sobel operator outputs (VS1-VS5) and said global features (MOUT) for calculating a vertically-filtered value (Px) of said pixel (Px) depending on said global features (MOUT), said vertical Sobel operator outputs (VS1-VS5) and the values of said vertically-neighboring pixels (Pe,Pf,Pg,Ph), and horizontal filter means (10) supplied with said global features (MOUT), said horizontal Sobel operator outputs (HS1-HS5) and said vertically-filtered value (Px) of said pixel (Px) for calculating a horizontally-filtered value of said pixel (Px) depending on said global features (MOUT), said horizontal Sobel operator outputs (HS1-HS5) and the vertically-filtered values (Pa,Pb,Px,Pc,Pd) of said pixel (Px) and said horizontally-neighboring pixels (Pa,Pb,Pc,Pd).

20. Device according to claim 19, characterized in that said vertical filter means (9,D) comprises first fuzzy computation means (13) supplied with said vertical Sobel operator outputs (VS1-VS5) and said global features (MOUT) for evaluating degrees of coincidence (β1-β9) of the pattern of vertical Sobel operator outputs (VS1-VS5) with a set of predefined patterns of vertical Sobel operator outputs, said degrees of coincidence (β1-β9) depending on said global features (MOUT), a look-up table of predefined vertical filter coefficients (F1-F9) each one associated to at least one respective predefined pattern of vertical Sobel operator outputs, a vertical filter coefficients composition means (14) supplied with said predefined vertical filter coefficients for generating a set of vertical filter coefficients (V1-V5) which are a weighted average of the predefined vertical filter coefficients with weight coefficients formed by said degrees of coincidence (β1-β9), and a vertical filter (15) supplied with said vertical filter coefficients (V1-V5) and

the values of the pixel (Px) and the vertically-neighboring pixels (Pe,Pf,Pg,Ph) for providing at an ouput (FOUT) said vertically-filtered value of the pixel (Px).
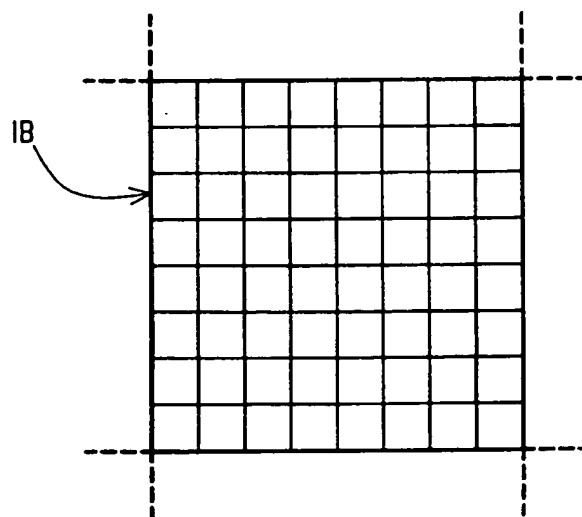
21. Device according to claim 20, characterized in that said horizontal filter means (10) comprises second fuzzy computation means (13) supplied with said horizontal Sobel operator outputs (HS1-HS5) and said global features (MOUT) for evaluating degrees of coincidence ($\alpha1$-$\alpha9$) of the pattern of horizontal Sobel operator outputs (HS1-HS5) with a set of predefined patterns of horizontal Sobel operator outputs, said degrees of coincidence ($\alpha1$-$\alpha9$) depending on said global features (MOUT), a look-up table of predefined horizontal filter coefficients (F1-F9) each one associated to at least one respective predefined pattern of horizontal Sobel operator outputs, a horizontal filter coefficients composition means (14) supplied with said predefined horizontal filter coefficients (F1-F9) for generating a set of horizontal filter coefficients (H1-H5) which are a weighted average of the predefined horizontal filter coefficients with weight coefficients formed by said degrees of coincidence ($\alpha1$-$\alpha9$), and a horizontal filter (15) supplied with said horizontal filter coefficients (H1-H5) and the vertically-filtered values (Pa,Pb,Px,Pc,Pd) of the pixel (Px) and the horizontally-neighboring pixels (Pa,Pb,Pc,Pd) for providing at an ouput (FOUT) said horizontally-filtered value (Out) of the pixel (Px).

Fig.1
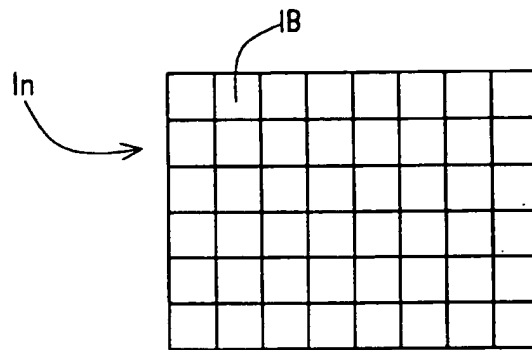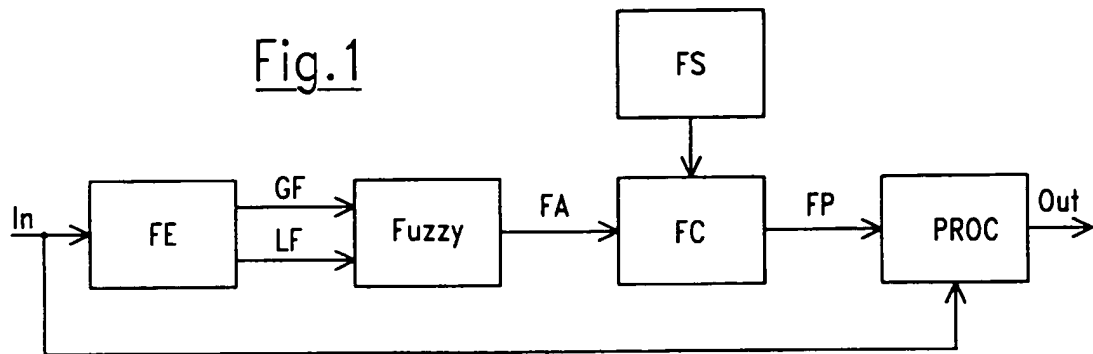
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                                    ┌──────┐
                                    │  FS  │
                                    └──┬───┘
                                       │
                                       ▼
     ┌──────┐  GF  ┌───────┐ FA ┌──────┐ FP ┌───────┐ Out
In ─→│  FE  │─────→│ Fuzzy │───→│  FC  │───→│ PROC  │───→
     │      │  LF  │       │    │      │    │       │
     └──────┘─────→└───────┘    └──────┘    └───────┘
        ▲                                       ▲
        │                                       │
        └───────────────────────────────────────┘
```

Fig.2

Fig.3

P1 P2 P3
P4 P1 P5
P6 P7 P8

IB

<u>Fig.4</u>

ISB

IB

<u>Fig.5</u>

HS1 HS2 HS3 HS4 HS5

Px Pc Pd

HPw

Pa Pb

IB

<u>Fig.6</u>

VS1
VS2
VPw
VS3
VS4
VS5

Pe
Pf
Px
Pg
Ph
IB

<u>Fig.7</u>

Small
1.0
Th1   Th2   HSi,VSi

<u>Fig.8</u>

Big
1.0
Th1   Th2   HSi,VSi

<u>Fig.9</u>
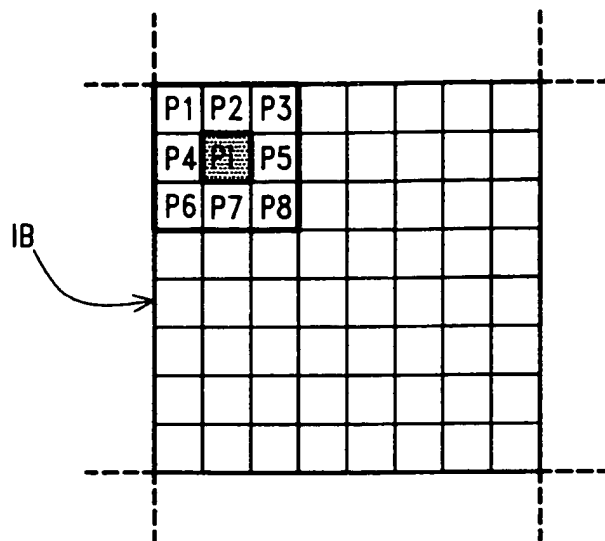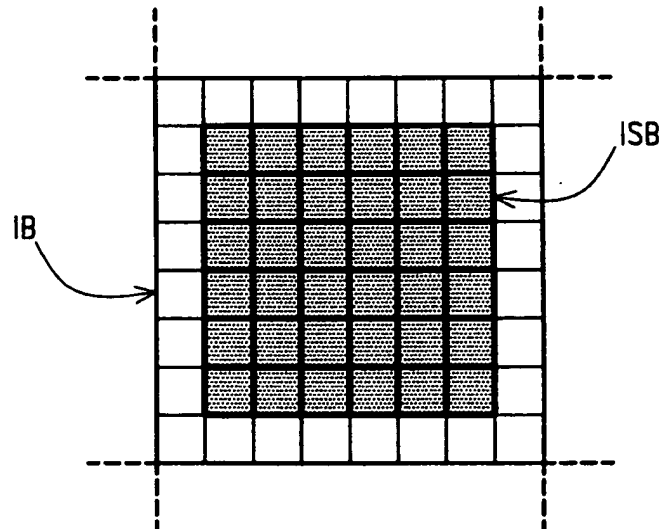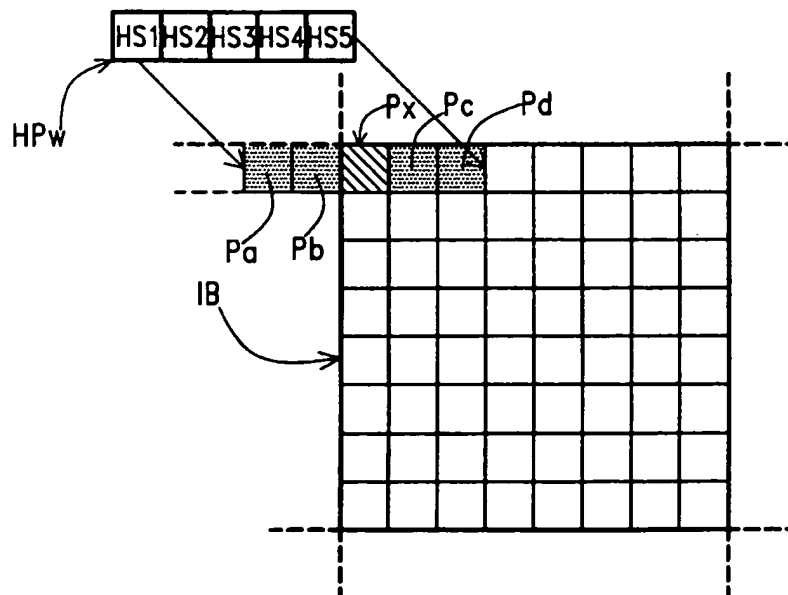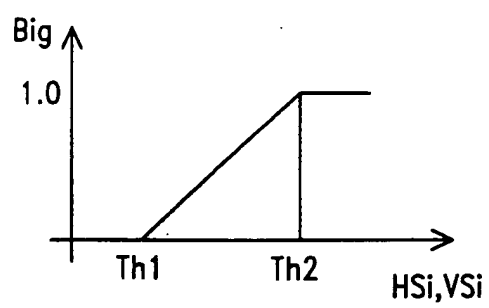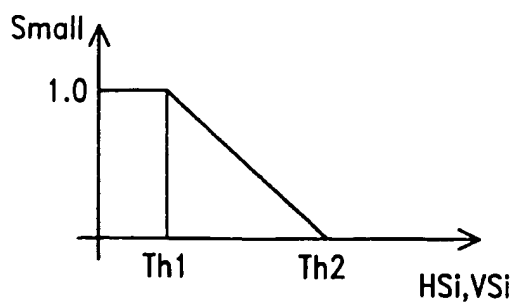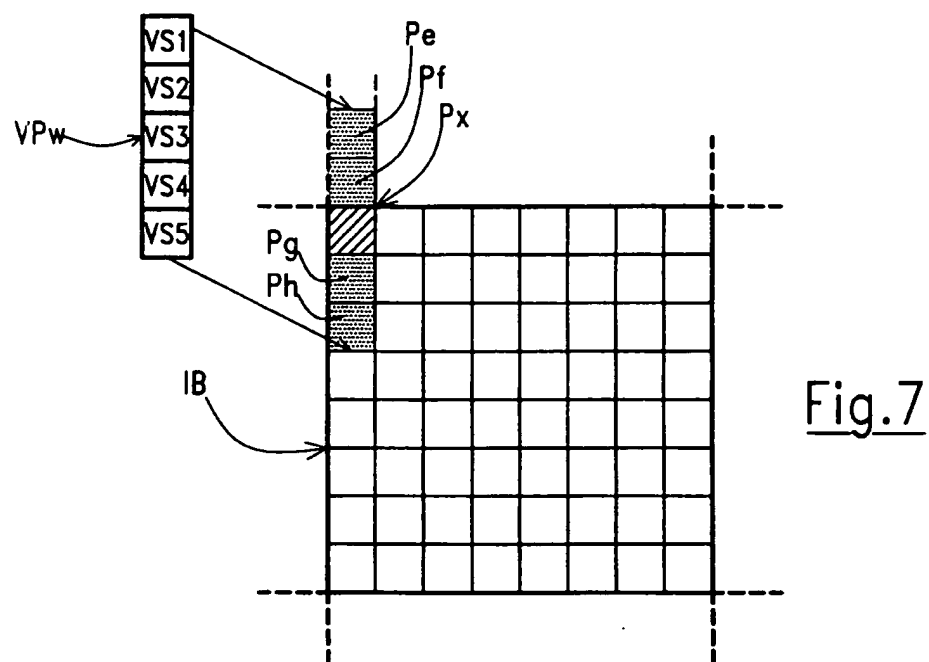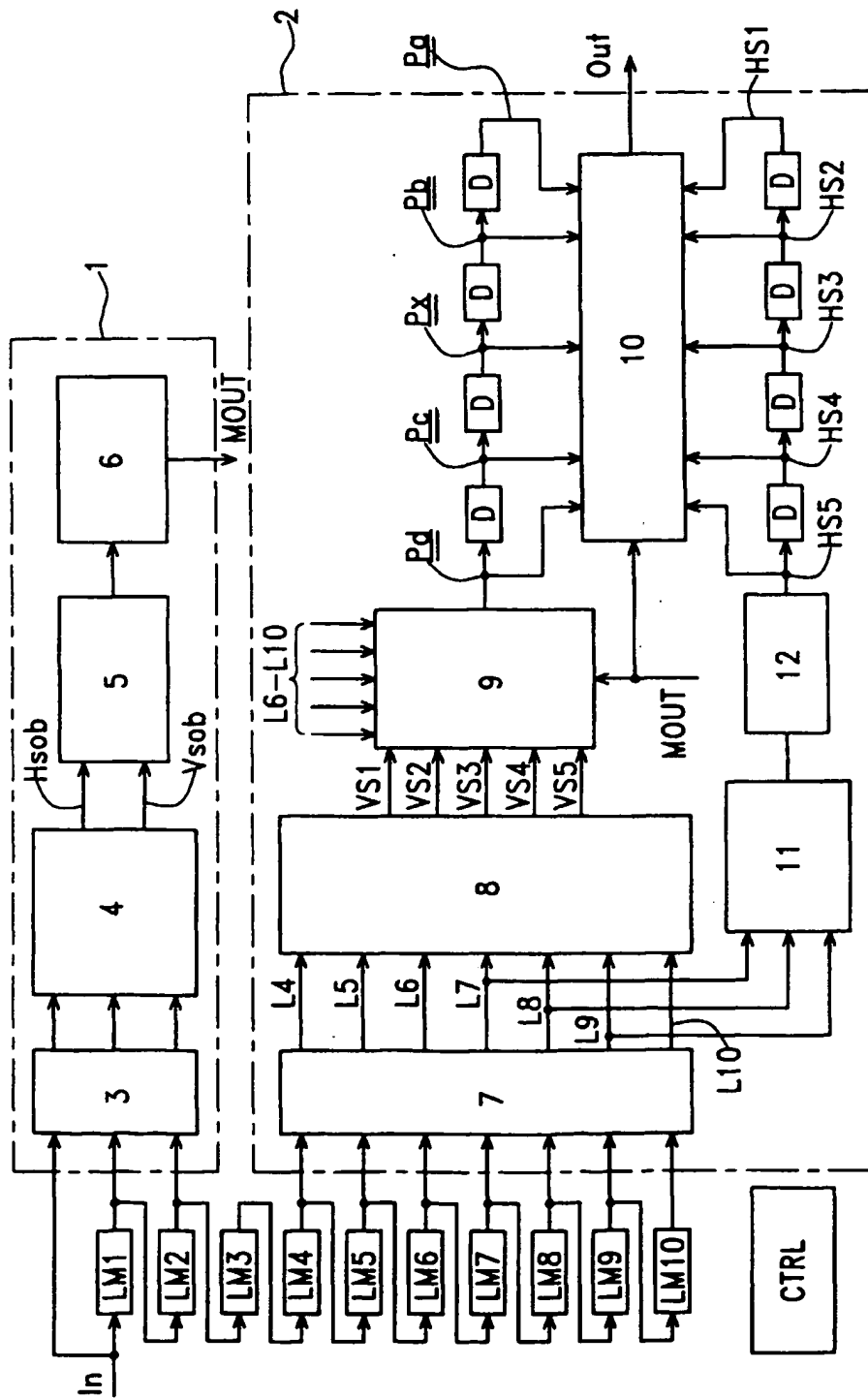
Fig.10

Fig.11

Fig.12

EUROPEAN SEARCH REPORT

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
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			H04N
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A		3-10, 17-19	

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	21 October 1997	Fassnacht, C

EP 0 881 837 A1

))) **European Patent Office**

EUROPEAN SEARCH REPORT

Application Number

EP 97 83 0264

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
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A	US 5 442 462 A (GUISSIN RAMI) 15 August 1995 * column 12, line 42 - column 12, line 53 *	1-21	TECHNICAL FIELDS SEARCHED (Int.Cl.6)
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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
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